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ASSESSMENT OF THE GROWTH AND RECOLONIZATION OF *FUCUS* IN NORTON SOUND, ALASKA

By

Gene J. Sandone

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Alaska Department of Fish and Game
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ABSTRACT

Area recolonization and population recovery of rockweed kelp (*Fucus sp.*) was evaluated in southern Norton Sound after simulated man-induced perturbations. Kelp (*Fucus*) beds, which were subjected to simulated harvest of spawn-on-kelp recovered to control or undisturbed conditions after one growing season (June - September 1984) in biomass, percent cover, and number of large plants per unit area. Beds subjected to removal of all plants required two growing seasons (June 1984 - August 1985) to recover to control conditions.

The present study provides a basis for concluding that annual harvests of spawn-on-kelp from the same kelp bed will not have detrimental effects on *Fucus* population size or structure in southern Norton Sound.

KEY WORDS: *Fucus sp.*, Rockweed kelp, recolonization, spawn-on-kelp harvest, Bering Sea herring

INTRODUCTION

Pacific herring (*Clupea harengus pallasi*) spawn in Norton Sound (Figure 1) annually between mid-May and late June. Herring deposit their adhesive eggs primarily on kelp (*Fucus sp.*) and inorganic substrates in the intertidal and sub-tidal zones of the shoreline. Embryos usually hatch within 15 to 20 days depending on water temperatures (Outram 1985). Aerial survey observations of herring milt releases, in conjunction with *in situ* spawn and spawn substrate surveys, have indicated that the major herring spawning grounds in Norton Sound occur within the St. Michael Subdistrict of southern Norton Sound (Figure 2).

The commercial harvest of herring spawn-on-kelp was initiated in Norton Sound in 1977 with the delivery of less than 1.0 tonne (metric ton). The harvest increased in subsequent years, peaking in 1981 with a documented harvest of 42.2 tonnes (Table 1) (Lebida et al. 1985). The commercial harvest of spawn-on-kelp was prohibited in Norton Sound by regulation in 1985 (ADF&G 1985). Total estimated value of the annual harvest to the fishermen has varied from $2,723 in 1978 to $73,000 in 1980 (Table 1). The contribution of the spawn-on-kelp harvest to the total ex-vessel value of the Norton Sound commercial herring fishery has ranged from 2% in 1979 and 1984 to 45% in 1978. However, during the final years of the fishery (1981 - 1984) the spawn-on-kelp harvest contributed less than 6% to the total ex-vessel value of the Norton Sound commercial herring fishery.

Both the sac roe and spawn-on-kelp herring fisheries of Norton Sound have been managed under emergency order authority and set guideline harvest levels in order to prevent overexploitation of the herring resource and to provide for an orderly and annual sustained harvest. Initial in-season management regulation of the herring spawn-on-kelp fishery commenced in 1981 with the emergency closure of the commercial season by the Alaska Department of Fish and Game (ADF&G). In subsequent years, both the opening and closing of the fishery were regulated by emergency order authority. An area-specific closure around Stuart Island (Figure 2), initiated prior to the 1980 commercial season, limited the area open to the commercial harvest of spawn-on-kelp in Norton Sound (ADF&G 1980). This closure was specifically designed to protect the subsistence spawn-on-kelp harvest (C. Lean, Alaska Department of Fish and Game, Nome, personal communication). Subsequently, an additional area between Wood Point and the mouth of Wagon Box Creek (Figure 2) was closed to the taking of herring spawn-on-kelp prior to the 1981 commercial fishery (ADF&G 1981). This closure was designed to protect the *Fucus* resource from overexploitation (C. Lean, Alaska Department of Fish and Game, Nome, personal communication). In 1982 this area-specific closure was extended to include the coastal area between Wood Point and Golsovia River (Figure 2). A 30-tonne spawn-on-kelp harvest guideline for the coastal area between Canal Light Point and Wood Point in southern Norton Sound was also adopted by the Alaska Board of Fisheries prior to the 1982 commercial herring fishing season (ADF&G 1982). Commercial harvest of spawn-on-kelp was prohibited by Alaska Board of Fisheries by regulation in the Norton Sound District commencing with the 1985 herring season (ADF&G 1985). This fishery closure was in response to public concerns regarding the possible overexploitation of the herring resource (L.J. Schwarz, Alaska Department of Fish and Game, Kodiak, personal communication).

In 1978 ADF&G began intensive studies of the *Fucus* resource in the Togiak area of Bristol Bay (Figure 3) in response to concerns of possible overexploitation of *Fucus* in the intertidal and subtidal zones (Clark and Buklis 1978; McBride et al. 1982). Based upon a subsequent study pertaining to the growth and recolonization of *Fucus* in Bristol Bay, Stekoll et al. (1984) recommended that a harvested bed be closed for two growing seasons to allow the plants to recover to pre-harvest biomass and plant size-frequency distribution levels.

Southern Norton Sound, specifically the vicinity of Leibes Cove near the village of St. Michael (Figure 2), supported a large portion of the annual commercial spawn-on-kelp harvest from the inception of the fishery until its suspension in 1985. Concern was expressed within the Department and by members of the public concerning the possible degradation and/or decimation of the *Fucus* resource by the repeated annual harvest of herring spawn-on-kelp from this area. Although Norton Sound is presently closed to the commercial harvest of herring spawn-on-kelp, future commercial harvests are possible through reconsideration of the enacted regulation by the Alaska Board of Fisheries.

The intertidal plant community of Norton Sound, which is dominated by *Fucus*, appears to be continually threatened by the harsh environmental conditions of Norton Sound. Ice scour, intensive wave action, freeze desiccation, and possible slow growth and recolonization rates due to the cold temperatures and short growing season, are factors which may inhibit *Fucus* survival in Norton Sound. Concern has been expressed that repeated and continued annual commercial harvest of spawn-on-kelp from the same specific area in conjunction with other natural factors may eliminate local populations of *Fucus*. Elimination or degradation of the *Fucus* beds within the major spawning grounds would in turn decrease herring spawning success.

The present study was initiated to determine the growth and recolonization rates of *Fucus* and is intended to provide information on the effects of repeated annual spawn-on-kelp harvests on the *Fucus* population in Norton Sound. Additionally, the results of this study will be used to formulate management strategies for possible future commercial spawn-on-kelp fisheries. The specific objectives are to:

1. determine the response of the *Fucus* biomass to harvest (simulated spawn-on-kelp harvest) and removal (denude area) treatments;

2. determine *Fucus* recolonization rates of denuded areas (removal treatment); and

3. determine the growth rates of individual *Fucus* plants under natural conditions.

METHODS

Recovery and Growth

Three 50 m study transects were established in the St. Michael Subdistrict during 1984. Transects were established near Klikitarik Point on June 26; near Twin Islands approximately eight miles east of Klikitarik Point in the Black Point area on June 28; and near Myouchuk Point (Figure 2), approximately 2 miles west of Klikitarik Point on September 13. The transect located near Myouchuk Point was completely destroyed by ice scour during the 1984-85 winter, and no data were obtained. Selection of transect location was dependent upon uniformity of the bed and the topography of the rock substrate. All transects were located within the lower half of the intertidal zone. Individual transects were defined by headpins epoxyed into the rock substrate. Transect headpins were located measured distances and directions from either obvious landmarks or established fence posts.

Each study transect consisted of eighteen 0.25 m^2 plots, randomly distributed along the transect, with three treatments randomly distributed among plots. Treatment included: removal of all vegetation from the plot (removal treatment); removal of plants greater than approximately 5 cm in length to simulate a commercial herring spawn-on-kelp harvest (harvest treatment); and no disturbance to the vegetation (control treatment). The harvest treatment was assumed to at least replicate the degree of damage done to the *Fucus* bed by a spawn-on-kelp harvest. Each plot was defined by epoxy cement markers on at least two corners. Individual plots were identified by a numbered Petersen disc tag glued on one of the marked corners.

Prior to initial experimental treatment of plots and during subsequent sampling periods, percent cover, and depth of *Fucus* as it lay undisturbed on the substrate was estimated and measured, respectively, for each plot within the Klikitarik Point and Twin Islands transects. Estimates of percent cover were made by either assessing the plot as a whole, or by calculating the mean of several partial subplot estimates. Additionally at this time, the depth of undisturbed *Fucus* was measured (nearest 0.5 km) at 25 equidistant locations within each plot for all plots. Mean (arithmetic and geometric) depths were used to estimate the *Fucus* biomass within a plot through the relationship between known biomass, percent cover, and mean depth of the kelp plants of plots.

Prior to initial treatment all plots were assumed to have been previously undisturbed. Therefore, *Fucus* biomass, plant number, and plant length data collected from 11 of the 12 designated removal treatment plots during the initial treatment of the virgin plots were considered representative of initial control conditions. The *Fucus* biomass removed from one of the removal treatment plots during initial treatment appeared dead due to the fresh water influence of melting ice. Therefore, the biomass of this plot was discarded and not used in further analysis. Plant length was measured to obtain baseline length frequency distribution data, which has been suggested as an important factor in determining the condition of a previously harvested *Fucus* population (Stekoll et al. 1984). Plant size was also used to determine the baseline number of plants per plot which were of harvestable size ($\geq$ 10 cm total length). Percent *Fucus* coverage of the June 1984 treatment plots (control, harvest, and removal), was derived from the respective treatment plots.

McConnaughey (1985) recommended that 2 to 3 years be allowed between harvests on individual *Fucus* beds in Bristol Bay. Therefore, the present study was designed for three growing seasons with a third of the treatment plots reassessed for biomass and length frequency distribution each year. Since the assessment destroyed all kelp plants growing within the sampled plot, all transects would be exhausted of initially treated plots after three sampling periods. However, ice scour during the winter and spring months damaged the definitions of some plots reducing the number available. Therefore, the study terminated after two growing seasons due to the lack of undisturbed study plots for analysis.

Sampling periods were based on the end of the growing season in Norton Sound. *Fucus* growth was assumed to have effectively ended by late August or early September due to decreasing temperatures and photoperiod. Therefore, sampling of *Fucus* plots and plant measurements were conducted on September 11 and 12, 1984 and August 27 through 31, 1985.

During the September 1984 and August 1985 sampling periods, four plots from each initial treatment group (control, harvest, and removal) were randomly selected for assessment of the *Fucus* population. However, higher than normal low tides during the September 1984 sampling period precluded the sampling of some selected plots. Therefore, only three plots from each treatment were sampled during the September 1984 period. The September 1984 and August 1985 assessments were assumed to reflect the growth of *Fucus* within the experimental plots after one and two growing seasons, respectively. All plants within plots selected for sampling were physically removed. The plants from each plot were collectively weighed (nearest 1 g) to determine biomass, individually measured (nearest 0.5 cm), and enumerated. Plant length frequency distributions were constructed. Number of plants equal to or greater than 10.0 cm, or large plants, was noted. On occasion, due to the great number of plants in some plots, a subsample of plants was taken for measurement purposes. These data were subsequently expanded based on the entire sample. All subsamples consisted of at least 25% of the total plot biomass.

Individual Plant Growth

One hundred twenty (120) individual *Fucus* plants were located and measured, number of blades enumerated, maturity noted, and overall condition assessed during June 1984. Sixty (60) of these plants were tagged within the intertidal zone at Klikitarik Point. The remaining sixty (60) plants were located near the study transect at Twin Islands (Figure 2). At each location ten (10) plants were selected within each of six size categories for study. The six size categories were as follows: 20-59 mm; 60-99 mm; 100-139 mm; 140-179 mm; 180-219 mm; and greater than 219 mm. A Petersen disc tag was secured with epoxy cement onto the rock substrate a measured distance and direction from the plant to facilitate relocation. A line transect was established through the tagged plant area and the disc tags were located by their measured distance along, and vertical distance off the transect line.

In June 1985 an additional 120 plants were tagged near Klikitarik Point and Twin Islands to increase sample size number. However, due to the difficulty experienced in relocating many of the plants tagged in 1984, an additional Floy tag was cemented to the rock substrate so the end of the Floy tag nearly touched the sampled *Fucus* plant. Similar to the tagged plant study initiated in 1984, the tagged plants were equally divided by location into the six previously defined size categories. All tagged plants were located within the lower half of the intertidal zone.

During the period of initial plant location, identified plants were measured (nearest 1 mm), number of blades enumerated, and general maturity noted (gravid with swollen receptacles or not gravid). For the purposes of this study, a blade was defined as a dichotomy separated from the next nearest dichotomy by more than one third of its length (McConnaughey, 1985). Since *Fucus* plants are gravid in the spring months, general maturity of plants was noted to determine the minimum size of mature and gravid plants. Only plants which were considered at least in good condition were selected as study plants. Plants initially tagged during June 1984 and June 1985 were relocated and subsequently sampled for linear growth and number of blades during September 1984 and August 1985, respectively. Hence, mean growth increments can also be expressed as growth rates based upon one growing season. Due to breakage of plants between initial tagging and subsequent reassessment some plants incurred a negative growth increment. For purposes of this report, mean gross growth increments were calculated from positive and negative growth values while the mean net growth increments were calculated from only the positive growth increment values. Gross growth was considered an indicator of overall plant population growth while net growth was considered an conservative estimate of potential or maximum growth.

Statistical Analysis

Stepwise multiple linear regression analysis was used to determine the best model for nondestructively estimating *Fucus* biomass from all plots during each sampling period and prior to experimental treatment. Actual biomass measurements after removal of all plants from sampled plots were regressed on percent cover and the mean (arithmetic and geometric) depth of *Fucus* as it lay undisturbed on the substrate of all sampled plots. Acceptability of the model required a significant ($P < 0.10$) relationship between independent and dependent variables and that the coefficient of determination (r^2) was at least equal to 0.80.

Analysis of variance (ANOVA) was used to determine if significant differences in plant biomass, cover, total number of plants, and number of large plants (plants equal to or greater than 10 cm) occurred among plot treatments. ANOVA was also employed to determine if significant differences occurred among sampling periods for each treatment for each of the aforementioned biological parameters. If ANOVA indicated that significant differences occurred among treatments or time periods, then the Least Significant Difference (LSD) multiple mean comparison test (STSC 1985) was used to explore which of the means were significantly different. A chi-square goodness-of-fit test was used to determine significant differences in the length frequency of *Fucus* plants among treatment plots and within treatments among sampling periods.

Individual plant growth measurements for each size classification were pooled for the two sampling periods to obtain a better representation of plant growth over the duration of the study. Analysis of individual plant growth data included ANOVA by plant size category using gross growth measurements, which included positive as well as negative growth increments, and also net growth measurements, which included only positive growth increments. Significant size differences between the size classes were determined using the LSD comparison test of means.

Analysis of blade number includes only plants initially tagged and subsequently reassessed in 1985. Data collected in 1984 were not used in the analysis due to sampling associated with a poor plant blade definition. Statistical analyses, similar to the tests used to determine significant differences among and between size categories for linear plant growth, were employed to test for significant differences among and between plant size classes assessed for plant blade number changes between June and August 1985. However, due to the small sample size of plants assessed for blade numbers these results should not be construed to apply to the total *Fucus* population.

RESULTS

Recovery and Growth

Nondestructive Biomass Assessment

Although a significant relationship was detected between biomass, cover and depth of vegetation ($P < 0.01$) (biomass = -682.9 + 13.1 [cover] 233.2 [arithmetic mean of the depth of the vegetation]), the coefficient of determination (r^2) value of 0.62 was considered unacceptable. Because the nondestructive biomass estimate was considered too imprecise for the purposes of this study, plot biomass assessment was carried out by the removal and collective weighing method. McConnaughey (1985) used a similar nondestructive method to estimate volume of *Fucus* within a plot, but he also indicated that the technique was problematic and error-prone.

Pretreatment Plot Measurements

Percent *Fucus* coverage was assessed in all plots in their virgin condition in June 1984 before treatments were applied. Mean percent *Fucus* coverage of all plots ranged from 58.8% in the designated harvest treatment plots to 78.8% in the designated removal treatment plots (Table 2) before initial treatments were applied. ANOVA indicated that significant differences in percent coverage existed among the pretreatment plots ($P = 0.08$). LSD analysis for pairwise comparisons further indicated that the coverage of the designated harvest and removal treatment plots differed significantly prior to treatment. However, neither the pretreated harvest nor the pretreated removal treatment plots differed significantly from the percent *Fucus* coverage of the designated control plots prior to treatment (Table 2). Differences in number of plants and biomass of harvest and control plots prior to treatment could not be determined using non-destructive methods. However, initial control conditions, regarding total number of plants, number of large plants, and biomass, were monitored using the *Fucus* biomass obtained from the virgin removal treatment plots in June 1984 (Table 3).

Control Treatment Plot Measurements

Fucus cover of control plots did not significantly vary throughout the study period ($P = 0.56$); nor did the number of large plants ($P = 0.81$), nor *Fucus* biomass within plots ($P = 0.81$). However, total number of plants per plot significantly differed by sample date ($P = 0.02$). The mean number of plants within control plots increased during the study period (Table 3). Mean number of plants per control plot was five times higher in August 1985 than the initial mean number observed in June 1984. Additionally, mean number of plants per plot in August 1985 was three times higher than in September 1984 (Table 3). However, the latter increase in plant numbers could be partially attributed to more complete and effective sampling of small plants in August 1985. Control plot data for the study period are summarized in Table 4.

Casual observations suggested that total number of plants increased in relation to the surface area of the plot covered by barnacles, regardless of the shading effect of larger plants (nonstatistical comparison = NSC). It appears that the rough surface of barnacle-covered substrate most likely retains more spores and affords a better nursery area for germlings than smooth rock. Substrate relief also differed among plots. Therefore, surface area available for plant colonization probably also differed. Since plot location and treatments were assigned on a random basis, the effect of barnacles and surface area on plant numbers was assumed to be nonsignificant across treatments and sampling periods. However, this hypothesis was not tested.

Mean length frequency distributions for June 1984, September 1984, and August 1985 control plots (Figure 4) were significantly different from each other ($P < 0.01$). However, since the number of large plants and *Fucus* biomass did not significantly differ in these plots over time, the temporal change in the length frequency distribution was probably attributable to the increased numbers of small plants.

Harvest Treatment Plot Measurements

No significant differences in total number of plants ($P = 0.31$), number of large plants ($P = 0.52$), and *Fucus* biomass ($P = 0.37$) were found between harvest treatment plots assessed during September 1984 and August 1985. Additionally, percent *Fucus* cover in pretreatment (virgin) harvest plots did not significantly deviate from the harvest treatment plots assessed in September 1984 and August 1985 ($P = 0.42$). The absence of significant differences between sampling periods indicates that harvest treatment plots stabilized in terms of all factors analyzed after only 1 growing season (June - September, 1984). Additionally, the absence of observed differences in percent cover of the virgin and treated plots indicate that *Fucus* biomass recovers quickly in terms of that measurement. Harvest treatment plot data for the study period are summarized in Table 5.

Removal Treatment Plot Measurements

Significant differences were observed in the number of large plants ($P < 0.01$), biomass ($P = 0.01$), and percent cover of *Fucus* ($P = 0.01$) in the removal treatment plots during the study period. However, total number of plants per plot remained relatively stable from the 1984 to 1985 sampling period ($P = 0.89$). Percent cover of the removal treatment plots sampled in September 1984 was reduced by approximately 30% over the initial pretreatment coverage of removal plots (Table 6). However, since the initial treatment removed all *Fucus* plants within the plot, these data could also be interpreted as a substantial increase in recolonization, as well as percent coverage, after only one growing season. Additionally, no significant difference in percent coverage was observed between the pretreated removal and the removal treatment plots sampled in 1985 (Table 6). These data indicate that *Fucus* coverage of the removal treatment plots returned to pretreatment levels after two growing seasons.

Mean number of plants greater than 10 cm and biomass in the removal treatment plots sampled in August 1985 also increased dramatically over removal treatment plots sampled the previous year (Tables 7 and 8, respectively). Numbers of large plants increased by a factor of 13, while biomass increased by a factor of approximately 7 between sample periods. Additionally, mean length frequency distributions (Figure 4) of removal plots sampled in September 1984 and 1985 were significantly different from each other ($P < 0.01$), further indicating the degree of change within the removal treatment plots during the study period. Removal treatment plot data for the study period are summarized in Table 9.

Percent cover and casual observations of the number of plants within plots cleared of all vegetation for two consecutive years indicated that recolonization by *Fucus* was similar to plots which received only one removal treatment (NSC).

Comparison of Fucus Response by Treatment

September 1984

Analysis of variance (ANOVA) indicated that significant differences occurred in the number of plants ($P = 0.045$), number of large plants ($P = 0.0346$), biomass ($P = 0.0405$), and percent cover ($P = 0.0729$) for plots by treatment sampled after one growing season, June - September 1984. The observed mean values for large plants, biomass, and percent cover of control treatment plots were significantly higher than from removal treatment plots (Table 10, 11, and 12, respectively). Similarly, mean values obtained from the harvest treatment plots were significantly higher than the removal treatment plots for large plants (Table 10) and percent cover (Table 12), respectively. Due to the high variability in biomass measurements and the small sample size of the harvest and removal treatment plots, significant differences in *Fucus* were not demonstrated between the harvest and removal treatment plots (Table 11).

Mean number of plants was significantly higher in the removal treatment plots than both the control or the harvest treatment plots (Table 13) indicating a significant recolonization response after the removal treatment. The mean number of *Fucus* plants which recolonized removal treatment plots was in excess of 2,300 during the first growing season after treatment. Although recolonization of denuded plots was substantial in terms of numbers of plants, these data indicate that the biomass and number of large plants of the removal treatment plot required more than one growing season to recover to control conditions. Significant differences between control and harvest treatment plots for plot coverage, number of plants, number of large plants and biomass were not demonstrated. The absence of significant differences between harvest and control treatment plots indicates that plot recovery, in terms of the above-mentioned parameters, was complete and stable after one growing season following the initial harvest treatment. Additionally, the absence of significant differences for the harvest treatment plots between the September 1984 and August 1985 sampling periods indicates that the harvest treatment plots remained stable after one growing season following initial treatment. A recovery period of no longer than one growing season for the harvest treatment plots is further supported by the absence of significant differences in percent cover for harvest treatment plots throughout the study.

August 1985

Differences among sampled treatment plots for total number of plants, number of large plants, biomass, and percent cover per plot were not significant ($P = 0.74$, $P = 0.13$, $P = 0.91$, and $P = 0.15$, respectively) two growing seasons after the initial treatment of the study plots. The complete recovery of the removal treatment plots to control and pretreatment conditions was most likely the direct result of a reduction in intraspecific competition among the *Fucus* plants for available sunlight. It appears that the periodic removal of large plants from a plot stimulates growth of smaller plants. The total removal of all plants initially stimulates growth of the germlings, which in two growing seasons rival the plants in the control plots in all parameters measured. The above analyses indicate that the harvest treatment plots remained stable after one growing season, while the removal treatment plots recovered to control conditions after two growing seasons.

Chi-square analyses of the 1985 length frequency distributions by treatment (Figure 4) were significantly different from each other ($P < 0.01$). Additionally, length frequency distributions of all control plots sampled over time (Figure 4) were also significantly different from each other ($P < 0.01$). Since control plots were undisturbed, differences in the length frequency distributions were due to natural disturbances. Apparently, due to the high degrees of freedom afforded by the great number of plants per plot, even slight naturally occurring changes in the distributions were significant. Therefore, since the length frequency distribution of control plots changed significantly through time and did not provide a stable parameter for comparison, this parameter should not be used as a criterion for recovery of harvest or removal plots.

Individual Plant Growth

Changes in individual plant length during the two study periods, June - September 1984, and June - August 1985, ranged from -186 mm to 128 mm (Figure 5). The overall mean gross growth increment per growing season or mean gross growth rates were 26.4 mm and 57.4 mm, respectively (Table 14). The greatest loss in plant length occurred in the larger plant size categories. Additionally, the number of plants which were observed to lose length increased as total plant length increased (Figure 5).

Mean plant size within size classes 20-59 mm, 60-99 mm, 100-139 mm, and 140-179 mm increased during the study period. Mean plant size decreased in two largest size classes. Mean gross growth increments, calculated from plants which demonstrated negative and positive growth, ranged from -22.7 per growing season in the largest category to 49.4 mm in the smallest size category. As stated earlier these growth increments were calculated based on plant growth during one growing season and, therefore, can also be considered growth rates for one growing seasons. ANOVA indicated that significant differences in mean gross growth rates existed among plant size categories ($P < 0.01$). Mean gross growth rates of the four smallest size categories were not significantly different from each other (LSD comparison test, $P > 0.10$). Likewise, the mean gross growth rates of the two largest size categories were not significantly different from each other. However, the four smallest size categories had significantly higher mean growth rates than the largest two size categories (Table 14).

ANOVA of the mean net growth rates by plant size categories was also conducted. The mean net growth rate or increment for each plant size class was calculated from measurements of plants which increased in size from initial measurement. This analysis was conducted in order to obtain an indication of the potential growth rate by size class based upon one growing season. ANOVA indicated that significant differences in mean net growth rates occurred among size classes ($P = 0.04$). LSD comparison of mean net growth indicated that the 100 - 139 mm size class had a significantly higher mean net growth rate than 4 of the 5 remaining size categories. The net growth rate of the 140 - 179 mm size category did not significantly differ from the lowest nor from the highest mean net growth rate (Table 14). Since minimal breakage of plants most likely occurred within the first two size classes, 20-59 mm and 60-99 mm, it appears that these two size classes have lower maximum growth rates than the 100-139 mm size class. This discrepancy in growth rates was most likely caused by the shading effect of larger plants on smaller plants. Since some breakage occurs in plants which have a positive growth increment the mean net growth increment should be viewed as a minimal estimate of potential or maximum growth. Because plant breakage occurs more often in the larger-sized plants it is difficult to estimate the potential growth of these plants.

Data collected from the 1985 tagging study were not used to determine the minimum plant size for sexual maturity since tagging of plants preceded the onset of the visible indications of plant sexual maturity during this period. Observation of the plant length data in conjunction with general maturity of the plants tagged in June 1984 indicates that no plants within the 20-59 mm size category were gravid. However, 45% of the tagged plants within the 60-99 mm size class were considered gravid. Over 80% of plants greater than 99 mm in length were considered gravid during the June 1984 tagging period. It appears that larger plants mature earlier in the season as evidenced by the extremely swollen condition of the their receptacles observed during sampling. Therefore, these data indicate that plants less than 60 mm most likely do not produce spores, while most plants equal to or greater than 60 mm are gravid during the spring.

Number of blades for plants assessed in June 1985 (Figure 6) increased in all but the 180-219 mm size class during the 1985 growing season (Table 15). Overall gross and net mean plant blade increase was 14.4 and 48.8, respectively, for the 1985 growing season (Figure 15). Generally, the proportional increase in blade numbers was more substantial in the smaller sized plants. Analysis of variance of gross and net plant blade increment per growing season by initial size classes indicated that significant differences in the change in plant blade number occurred ($P = 0.07$ and $P < 0.01$, respectively). Based upon LSD pairwise comparisons, plants in the 180-219 mm size category possessed significantly less blades than the four smallest plant size classes (Table 12).

Net changes in plant blade numbers per growing season, which included only the plants which had an increase in the number of blades from June to August 1985, were significantly higher for plants 140-179 mm and greater than 219 mm, than for plants between 20 and 139 mm and 180 and 219 mm (Table 14).

As stated above, the loss of plant material due to breakage can be more significant in larger plants. However, the potential increase in plant blade number in larger plants is great. It appears that potential increase in plant blade numbers could at least increase geometrically, depending upon the number of times one blade dichotomizes in a season. It also appears that there is a limit to the number of plant blades one plant can sustain. Similar to the maximum size of *Fucus* plants in Norton Sound, very few plants sampled in 1984 and 1985 had greater than 200 blades (Figure 6). Due to the small number of plants assessed, however, caution should be exercised when interpreting these analyses.

SUMMARY

1. Although a significant nondestructive biomass assessment model was generated, the coefficient of determination (r^2) value of the model was unacceptable. Therefore, *Fucus* biomass of study plots was determined by removal and weighing of all plants in the plot.

2. Control plots did not significantly vary over time with regard to percent cover, number of large plants, and biomass. Number of plants per plot did increase over time in control plots but were attributed to increased number of small plants and more thorough sampling effort.

3. Length frequency distributions of plants from control plots and initial pretreatment plots varied throughout the study period. Therefore, because of the instability in control plots length frequency distribution was not

used as a criterion for determining the status of experimental plots in relation to controls.

4. Significant differences did not occur for percent cover, total number of plants, number of large plants, and biomass between control and harvest treatment plots after one growing season. These data indicate that harvest treatment plots recovered to control conditions after only one growing season. After two growing seasons following initial treatment of the study plots, differences among all treatments for total number of plants, number of large plants, biomass, and percent cover were nonsignificant. This and the above analyses indicate that while harvest and control treatment plots remained statistically indistinguishable after one growing season subsequent to treatment, the removal treatment plots required two growing seasons to attain control levels.

5. Recolonization of removal treatment plots was rapid and complete. The mean recolonization rate was in excess of 2,300 plants per plot per growing season.

6. Individual *Fucus* plant growth was dynamic. Overall, plant length generally increased in small to medium sized plants, 20-180 mm, but degenerated in very large plants. Likewise, increases in plant blade number increased in plants less than 180 mm but tended to decrease or remain static in very large plants. *Fucus* plants greater than 100 mm probably lose a significant portion of their material due to breakage. Severe storm-induced wave action as well as ice scour in Norton Sound most likely are major causes of plant breakage. The overall mean gross and net growth rate was 26.4 mm and 57.4 mm per plant per growing season, respectively. The overall mean gross and net blade increment rate was 14.4 and 48.8 blades per plant per growing season, respectively.

DISCUSSION

In the present study, actual measurements of percent cover, biomass, and number of large plants appeared to be the best indicators of *Fucus* recovery after a man-induced perturbation. Data from the present study supports the conclusion that in Norton Sound recovery of a kelp bed from a man-induced perturbation, similar to a spawn-on-kelp harvest, to preharvest conditions will occur within one growing season.

Large plants, due to mutual shading, limit the recruitment and growth of smaller plants (McConnaughey 1985). As the population evolves to a climax state, biomass remains relatively stable. However, total number of plants decreases. McConnaughey (1985) stated that although a kelp bed in Bristol Bay recovered in terms of percent cover and wet weight in about one year, the succession of the community to a population of large, older, relatively sparse plants required two to four years. The present study presents evidence that a harvested kelp bed in Norton Sound will recover by the end of the summer of harvest (approximately 2.5 months) in terms of percent cover, biomass and number of large plants. While McConnaughey (1985) stated that the harvest treatment he used to simulate a spawn-on-kelp harvest was less severe than an actual spawn-on-kelp harvest, the harvest treatment employed in this study was at least as severe. However, McConnaughey (1985) proposed that two to three years lapse between harvests on a particular kelp bed. In the same study he surmised that areas subjected to periodic thinning would recover faster than areas left undisturbed for a number of years since perturbed areas would have a large number of smaller plants which would rapidly replace the plants removed. This assumption is also supported by the rapid and complete recovery in the present study of the harvest treatment plots.

Although spawn-on-kelp harvesters targeted on *Fucus* plants greater than 10 cm in length in the Togiak District of Bristol Bay, they were observed to have removed about the same mass of plant material independent of plant numbers or lengths, (McConnaughey 1985). It appears from the aforementioned observations that it is not necessary for the kelp plant to be greater than 10 cm to be harvested. Since individual *Fucus* plants have been observed to grow more than 10 cm in one growing season in Norton Sound (present study), it appears that annual harvests on the same kelp bed would have no detrimental consequences to the future standing stock of harvestable *Fucus* plants.

Observations of the removal treatment plots in the present study indicated that recolonization of *Fucus* on denuded areas is rapid and complete. Additionally, the total recovery of removal treatment plots after two growing seasons following initial treatment without a decrease in total plant numbers indicates that subsequent harvests would have little effect on the following year's standing stock of harvestable size *Fucus* plants. Therefore, it appears that there are no apparent reasons, relating to the biology of the *Fucus*, to restrict either the amount or the location of the harvest of spawn-on-kelp within southern Norton Sound. However, if a spawn-on-kelp fishery is re-introduced in Norton Sound, spawn-on-kelp harvest limits should be formulated based upon concern for herring spawn production.

Due to the relatively small number of plots assessed during this study, the major *Fucus* beds of Norton Sound should be assessed on a annual basis if a spawn-on-kelp fishery is re-introduced. Unlike the conclusions of the present study, recent observations of the *Fucus* resource in northern Norton Sound, specifically Elim and Golovin Subdistricts (Figure 1), indicate that northern Norton Sound could not support a spawn-on-kelp fishery due to the scattered distribution of the kelp beds and the low density of *Fucus* plants within the beds (D.C. Whitmore, Alaska Department of Fish and Game, Anchorage, personal communications).

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Table 1. Harvest, number of fishermen, and estimated value of the commercial spawn-on-kelp (*Fucus*) harvest in Norton Sound District, 1977 - 1985. (Adapted from Lebida et. al 1985.)

Year	Harvest (tonnes)	Number of Fishermen	Estimated Value ($)
1977	<1.0	?	?
1978	3.4	0	2,723
1979	11.8	19	15,576
1980	22.2	20	73,000
1981	42.2	22	45,000
1982	34.9	74	57,585
1983	26.5	35	38,500
1984	17.5	32	21,500[a]
1985[b]			

[a]Harvest of 3.0 tonnes of spawn-on-kelp from 0.91 tonne of imported *Macrocystis sp.* not included in the totals. Estimated value was $20,000.

[b]Commercial spawn-on-kelp harvest prohibited in Norton Sound by regulation.

Table 2. Mean percent cover by *Fucus* of plots by treatment (but before treatment), June 1984. (Mean percent values followed by different letters are significantly different, LSD test, $P < 0.10$.)

Treatment	Number of Plots	Mean Percent Cover	SD
Control	13	69.2 (a,b)	19.73
Harvest	12	58.8 (a)	24.64
Removal	12	78.8 (b)	16.67

Table 3. Mean number of *Fucus* plants in control plots by date, June 1984 - August 1985. (Mean values followed by different letters are significantly different, LSD test, $P < 0.10$.)

Date	Number of Plots	Mean Number of Plants	SD
June 1984	11	679.8 (a)	446.32
Sept. 1984	3	1,129.0 (a)	1,064.89
August 1985	4	3,452.0 (b)	3,177.36

Table 4. Mean percent plot coverage, total number of plants, number of large plants, and biomass of *Fucus*, control treatment plots, June 1984 - August 1985.

Treatment Dates	Plot Coverage: Number of Plots	Plot Coverage: Percent Cover	Plot Coverage: SD	Total Number of Plants: Number of Plots	Total Number of Plants: Mean Number Plants	Total Number of Plants: SD
June, 1984 (Pretreatment)	13[a]	69.2	19.73	11[b]	679.8	446.32
September, 1984	11	77.9	20.81	3	1,129.0	1,064.89
August, 1985	8	70.4	21.56	4	3,452.0	3,177.36

Treatment Dates	Total Number of Large Plants (≥ 10 cm): Number of Plots	Total Number of Large Plants (≥ 10 cm): Mean Number of Plants	Total Number of Large Plants (≥ 10 cm): SD	*Fucus* Biomass: Number of Plots	*Fucus* Biomass: Mean Biomass (g)	*Fucus* Biomass: SD
June, 1984 (Pretreatment)	11[b]	110.4	52.82	11[b]	1,166.0	698.07
September, 1984	3	102.7	75.25	3	909.7	427.26
August, 1985	4	88.5	61.54	4	1,035.0	514.99

[a]Control plots.
[b]Virgin removal treatment plots included for comparison. Associated data were collected from the virgin *Fucus* biomass removed from these plots. Therefore, these data were considered to represent initial control conditions.

Table 5. Mean percent plot coverage, total number of plants, number of large plants, and biomass of _Fucus_, harvest treatment plots, June 1984 - August 1985.

	Plot Coverage			Total Number of Plants		
Treatment Dates	Number of Plots	Percent Cover	SD	Number of Plots	Mean Number Plants	SD
June, 1984 (Pretreatment)	12[a]	58.8	24.64	11[b]	679.8	446.32
September, 1984	7	72.0	19.96	3	944.3	206.12
August, 1985	8	69.0	21.88	4	2,089.0	1,710.50

	Total Number of Large Plants ($\geq$ 10 cm)			_Fucus_ Biomass		
Treatment Dates	Number of Plots	Mean Number of Plants	SD	Number of Plots	Mean Biomass (g)	SD
June, 1984 (Pretreatment)	11[b]	110.4	52.82	11[b]	1,166.0	698.07
September, 1984	3	102.7	53.72	3	712.0	299.63
August, 1985	4	139.5	76.74	4	1,081.0	573.86

[a]Virgin harvest treatment plots.
[b]Virgin removal treatment plots included for comparison. Associated data were collected from the virgin _Fucus_ biomass removed from these plots. Therefore, these data were considered to represent pretreatment harvest plots or initial control conditions.

Table 6. Mean percent cover by *Fucus* of removal treatment plots by date, June 1984 - August 1985. (Mean percent values followed by different letters are significantly different, LSD test, $P < 0.10$.)

Date	Number of Plots	Mean Percent Cover	SD
June 1984	12	78.8 (a)	16.67
Sept. 1984	8	55.4 (b)	19.76
August 1985	6	89.2 (a)	12.73

Table 7. Mean number of *Fucus* plants greater or equal to 10.0 cm observed in the removal treatment plots by date, September 1984 and August 1985. (Mean number of plants followed by different letters are significantly different, LSD test, $P < 0.10$.)

Date	Number of Plots	Number of Plants	SD
Sept. 1984	3	12.7 (a)	11.15
August 1985	4	166.8 (b)	49.97

Table 8. Mean *Fucus* biomass of removal treatment plots by date, September 1984 and August 1985. (Mean biomass values followed by different letters are significantly different, LSD test, $P < 0.10$.)

Date	Number of Plots	Mean *Fucus* Biomass (g)	SD
Sept. 1984	3	184.3 (a)	142.23
August 1985	4	1,227.0 (b)	353.89

Table 9. Mean percent plot coverage, total number of plants, number of large plants, and biomass of *Fucus*, removal treatment plots, June 1984 - August 1985.

Treatment Dates	Plot Coverage: Number of Plots	Plot Coverage: Percent Cover	Plot Coverage: SD	Total Number of Plants: Number of Plots	Total Number of Plants: Mean Number Plants	Total Number of Plants: SD
June, 1984 (Pretreatment)	12[a]	78.8	16.67	11[b]	679.8	446.32
September, 1984	8	55.4	19.76	3	2,311.3	2,063.63
August, 1985	6	89.2	12.73	4	2,562.0	2,356.36

Treatment Dates	Total Number of Large Plants (≥ 10 cm): Number of Plots	Total Number of Large Plants (≥ 10 cm): Mean Number of Plants	Total Number of Large Plants (≥ 10 cm): SD	*Fucus* Biomass: Number of Plots	*Fucus* Biomass: Mean Biomass (g)	*Fucus* Biomass: SD
June, 1984 (Pretreatment)	11[b]	110.4	52.82	11[b]	1,166.0	698.07
September, 1984	3	12.7	11.15	3	184.3	142.23
August, 1985	4	166.8	49.97	4	1,227.0	353.89

[a]Virgin removal treatment plots.
[b]Virgin removal treatment plots. The biomass collected from one original removal treatment plot was discarded after collection since it appeared dead. Associated data were collected from the virgin *Fucus* biomass removed from removal treatment plots. These data are assumed to represent initial control conditions.

Table 10. Mean number of *Fucus* plants greater or equal to 10.0 cm per plot by treatment, September 1984. (Mean number of plants followed by different letters are significantly different, LSD test, $P < 0.10$.)

Treatment	Number of Plots	Number of Plants	SD
Control	18	104.2 (a)	55.31
Harvest	3	102.7 (a)	53.72
Removal	3	12.7 (b)	11.15

Table 11. Mean *Fucus* biomass per plot by treatment, September 1984. (Mean biomass values followed by different letters are significantly different, LSD test, $P < 0.10$.)

Treatment	Number of Plots	Mean *Fucus* Biomass (g)	SD
Control	18	1,094.2 (a)	604.23
Harvest	3	712.0 (a,b)	299.63
Removal	3	184.3 (b)	142.23

Table 12. Mean percent cover by *Fucus* of plots by treatment, September 1984. (Mean percent values followed by different letters are significantly different, LSD test, $P < 0.10$.)

Treatment	Number of Plots	Mean Percent Cover	SD
Control	11	77.9 (a)	20.81
Harvest	7	72.0 (a)	19.96
Removal	8	55.4 (b)	19.76

Table 13. Mean number of *Fucus* plants per plot by treatment, September 1984. (Mean number of plants followed by the different letters are significantly different, LSD test, $P < 0.10$.)

Treatment	Number of Plots	Mean Number of Plants	SD
Control	14	776.1 (a)	603.55
Harvest	3	944.3 (a)	206.12
Removal	3	2,311.3 (b)	2,063.63

Table 14. Mean length and gross and net linear growth increments of tagged plants by size category initially measured in June 1984 or 1985 and subsequently remeasured in September 1984 or August 1985, respectively. (Mean increment values followed by different letters, within columns, are significantly different, LSD test, $P < 0.10$.)

	Mean Plant Length											
	June 1984 & 1985			Sept. 1984 & Aug. 1985			Gross Increment[a]			Net Increment[b]		
Size Category (mm)	n	Mean Length (mm)	SD	n	Mean Length (mm)	SD	n	Mean Length (mm)	SD	n	Mean Length (mm)	SD
20 - 59	40	35.3	10.1	29	85.0	30.5	29	49.4 a	30.6	28	52.2 a	27.1
60 - 99	40	77.5	10.5	20	118.4	40.3	20	41.9 a	38.8	17	54.2 a	25.9
100 - 139	40	119.8	9.5	23	163.7	65.8	23	43.5 a	67.5	17	77.2 b	27.9
140 - 179	40	156.5	10.8	25	188.8	66.9	25	33.4 a	67.6	20	60.9 a,b	68.0
180 - 219	40	193.3	10.5	18	187.3	94.1	18	-5.2 b	95.8	13	44.0 a	41.3
> 219	40	245.7	22.0	20	221.6	85.7	20	-22.7 b	87.2	9	54.0 a	18.4
Total	240	130.1	71.3	135	156.5	79.9	135	26.4	70.2	104	57.4	30.4

[a]Includes both negative and positive linear growth increments.
[b]Includes only the positive linear growth increment.

Table 15. Mean number of plant blades and gross and net plant blade increments of tagged plants by size category initially enumerated in June and subsequently re-enumerated in August, 1985. (Mean increment value followed by different letters, within columns, are significantly different, LSD test, $P < 0.10$.)

	Mean Number of Plant Blades											
	June 1985			August 1985			Gross Increment[a]			Net Increment[b]		
Size Class (mm)	n	Mean Length (mm)	SD	n	Mean Length (mm)	SD	n	Mean Length (mm)	SD	n	Mean Length (mm)	SD
20 - 59	20	4.9	4.7	14	30.0	31.2	14	24.9 a	26.8	14	24.9 a	26.8
60 - 99	20	16.9	17.3	12	43.8	28.2	12	25.4 a	30.2	9	38.0 a	22.5
100 - 139	20	30.8	16.5	7	42.9	52.0	7	19.4 a	54.0	4	53.2 a	46.5
140 - 179	20	45.9	29.2	8	101.4	90.1	8	54.6 a	75.1	5	104.4 b	37.5
180 - 219	20	83.5	46.8	11	51.1	47.4	11	-35.2 b	61.8	4	25.0 a	24.5
> 219	20	138.7	61.1	9	145.0	146.5	9	4.7 a,b	115.4	5	95.2 b	52.4
Total	120	53.4	57.2	61	64.3	80.1	61	14.4	66.5	41	48.8	43.6

[a]Includes both positive and negative plant blade increments.
[b]Includes only the positive plant blade increments.

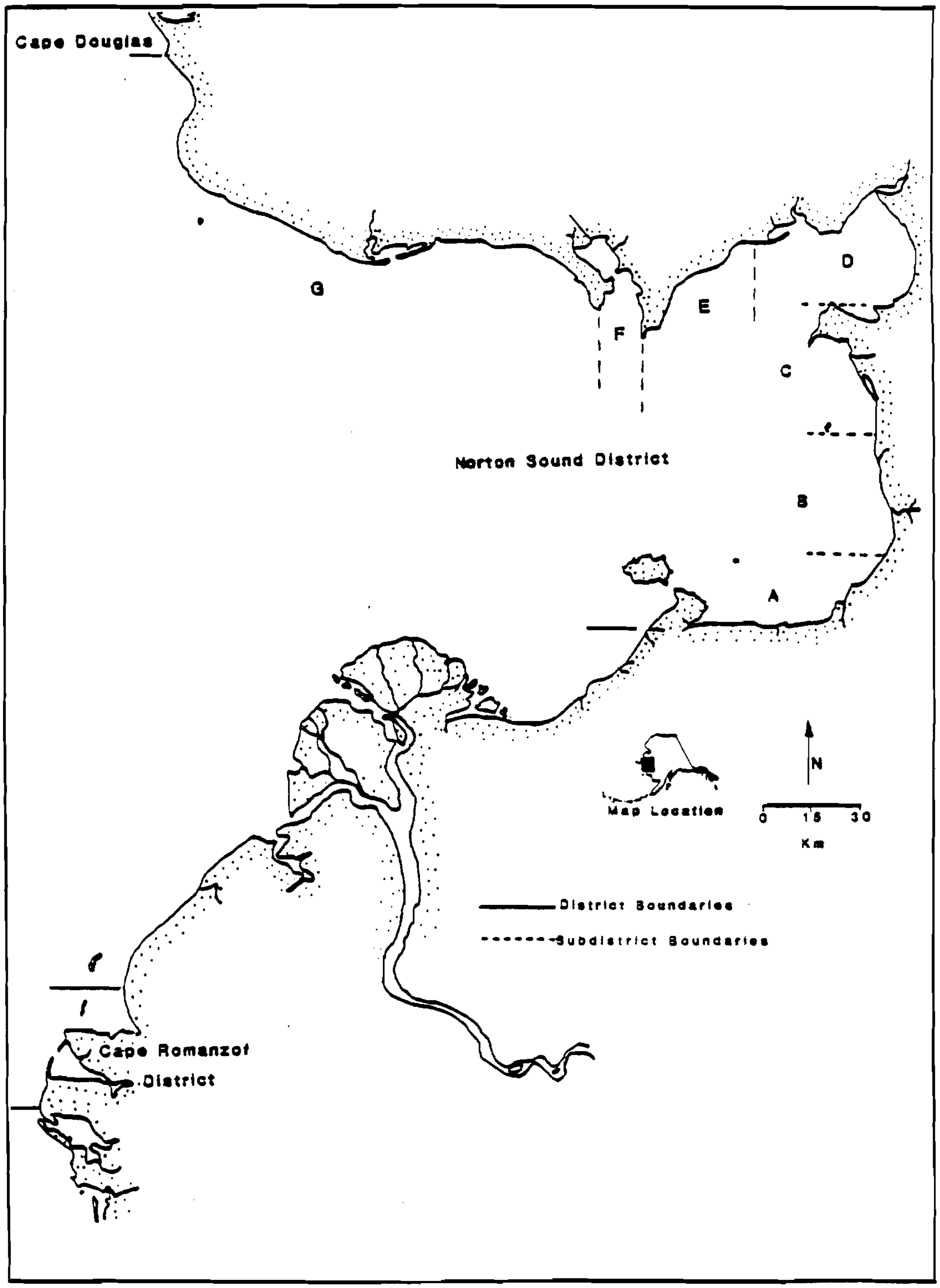

Figure 1. General location map, Norton Sound District, eastern Bering Sea, Alaska. (A = St. Michael, B = Unalakleet, C = Cape Denbigh, D = Norton Bay, E = Elim, F = Golovin Bay, and G = Nome Subdistricts.)

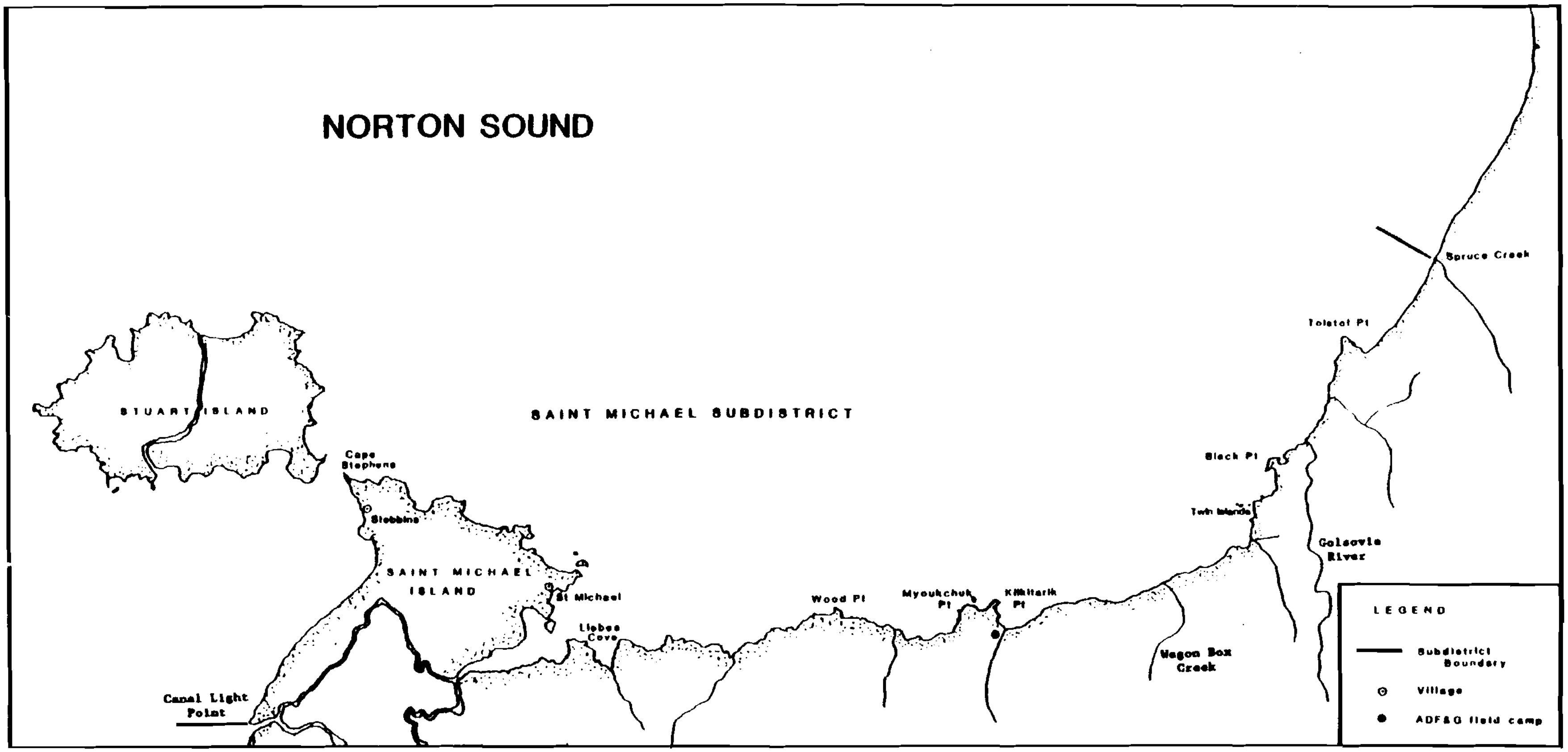

Figure 2. St. Michael Subdistrict, Norton Sound District, eastern Bering Sea, Alaska.

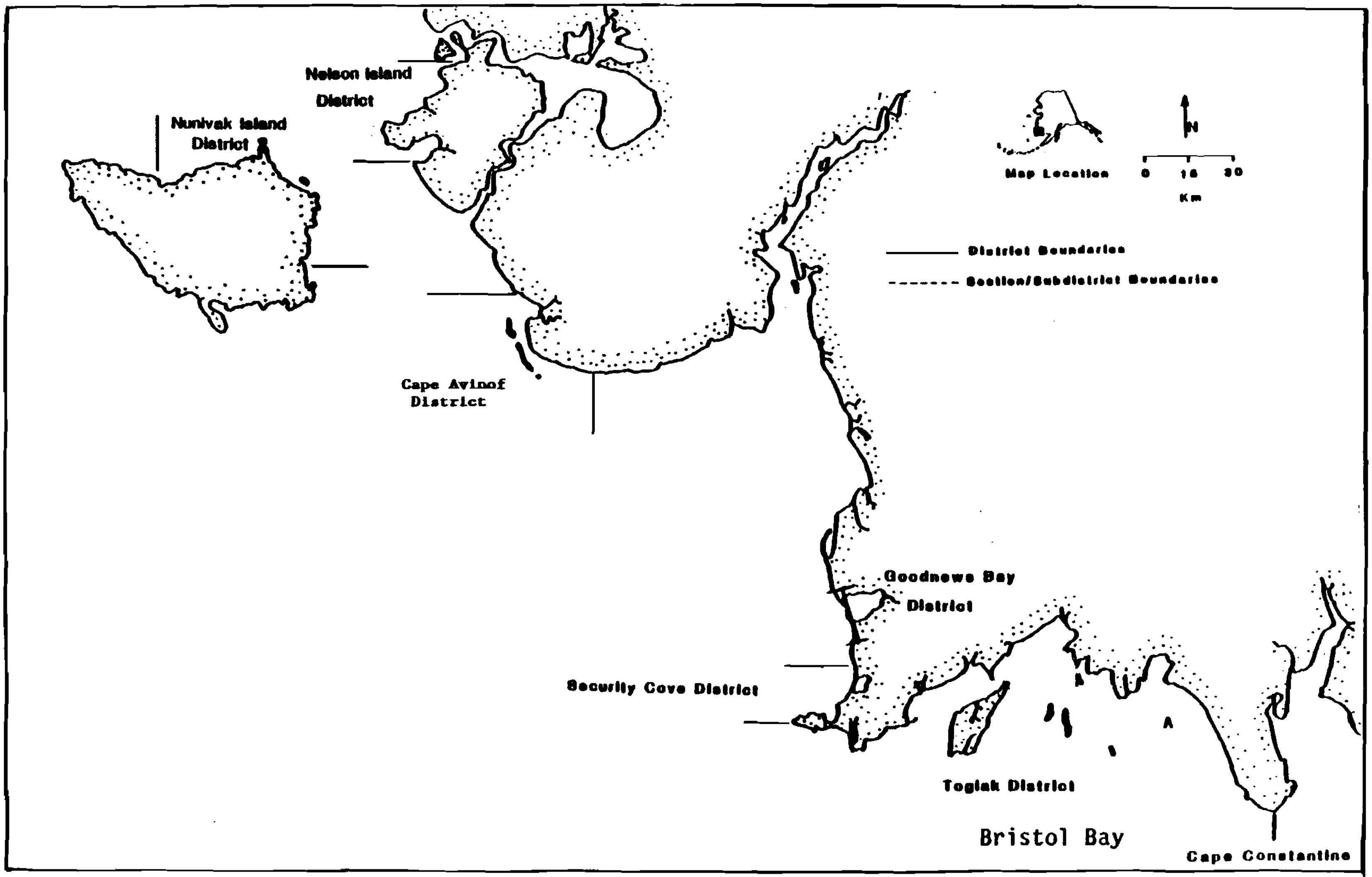

Figure 3. General location map, Togiak District, eastern Bering Sea, Alaska.

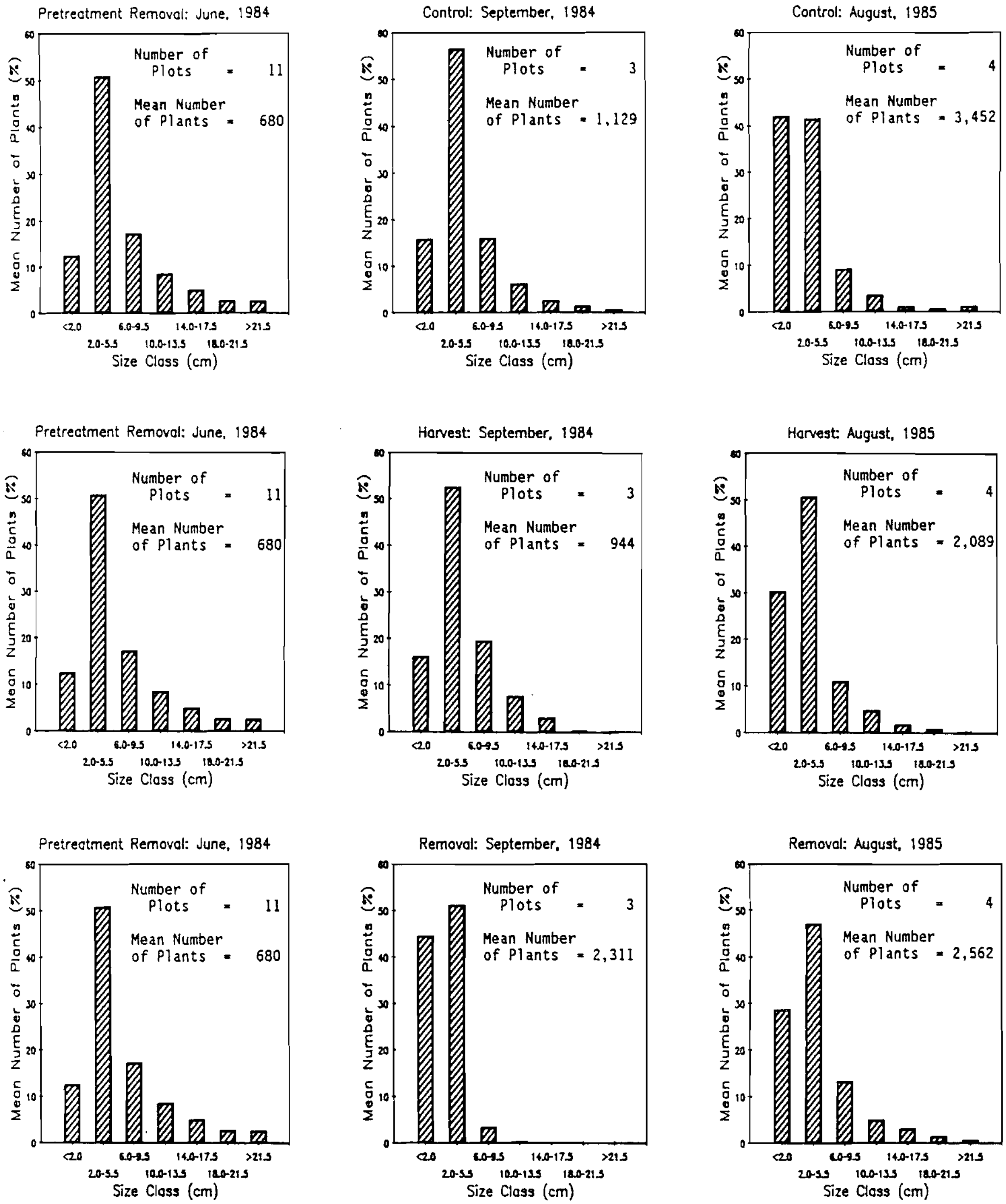

Figure 4. Mean length frequency distribution of *Fucus* plants from sampled control, harvest, and removal treatment plots, June, 1984 - August, 1985. (Note that data collected from the pretreatment removal plots in June, 1984 were assumed to represent initial control conditions.)

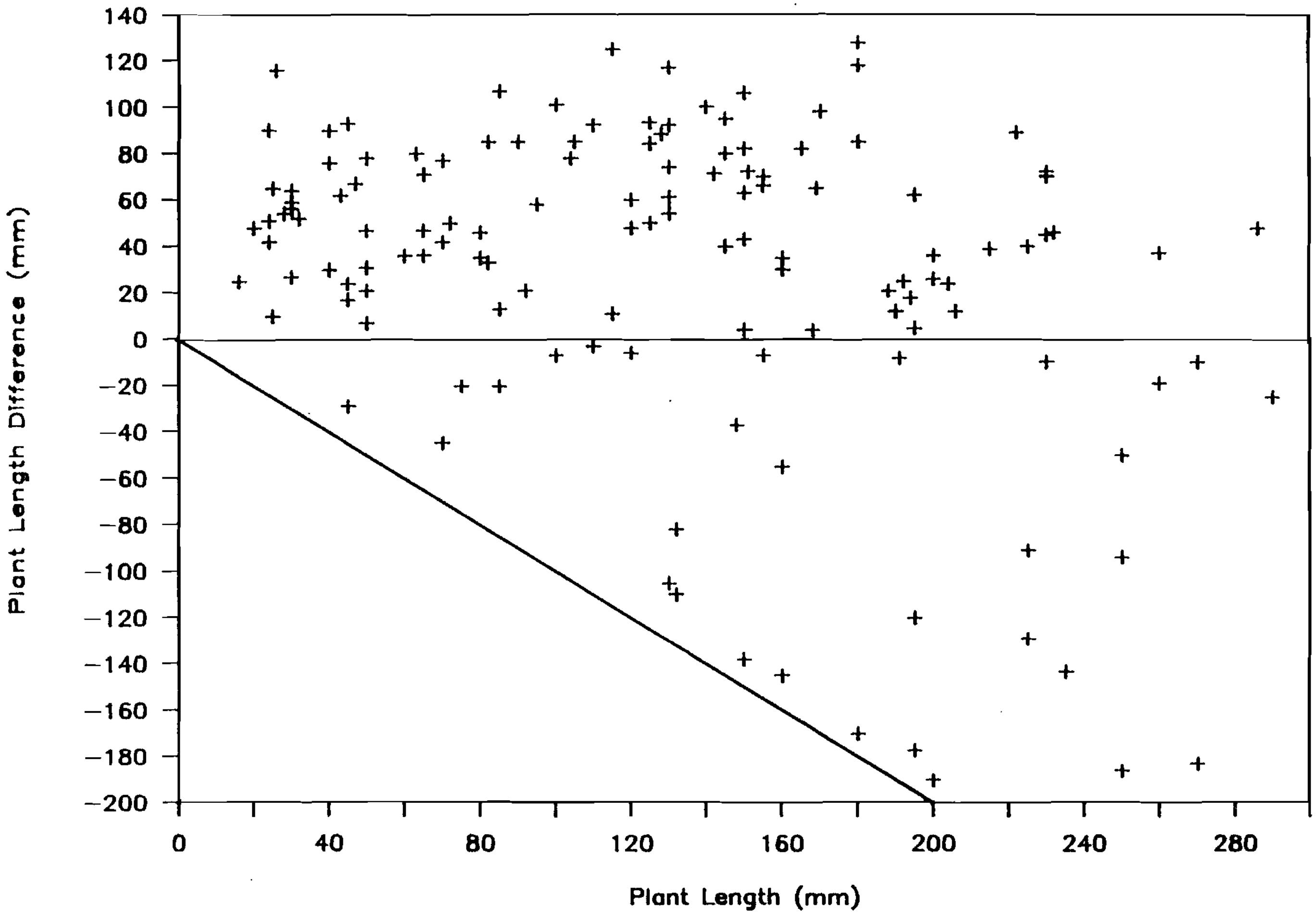

Figure 5. Scatter plot of the gross length difference of tagged *Fucus* plants between June and September, 1984 and June and August, 1985.

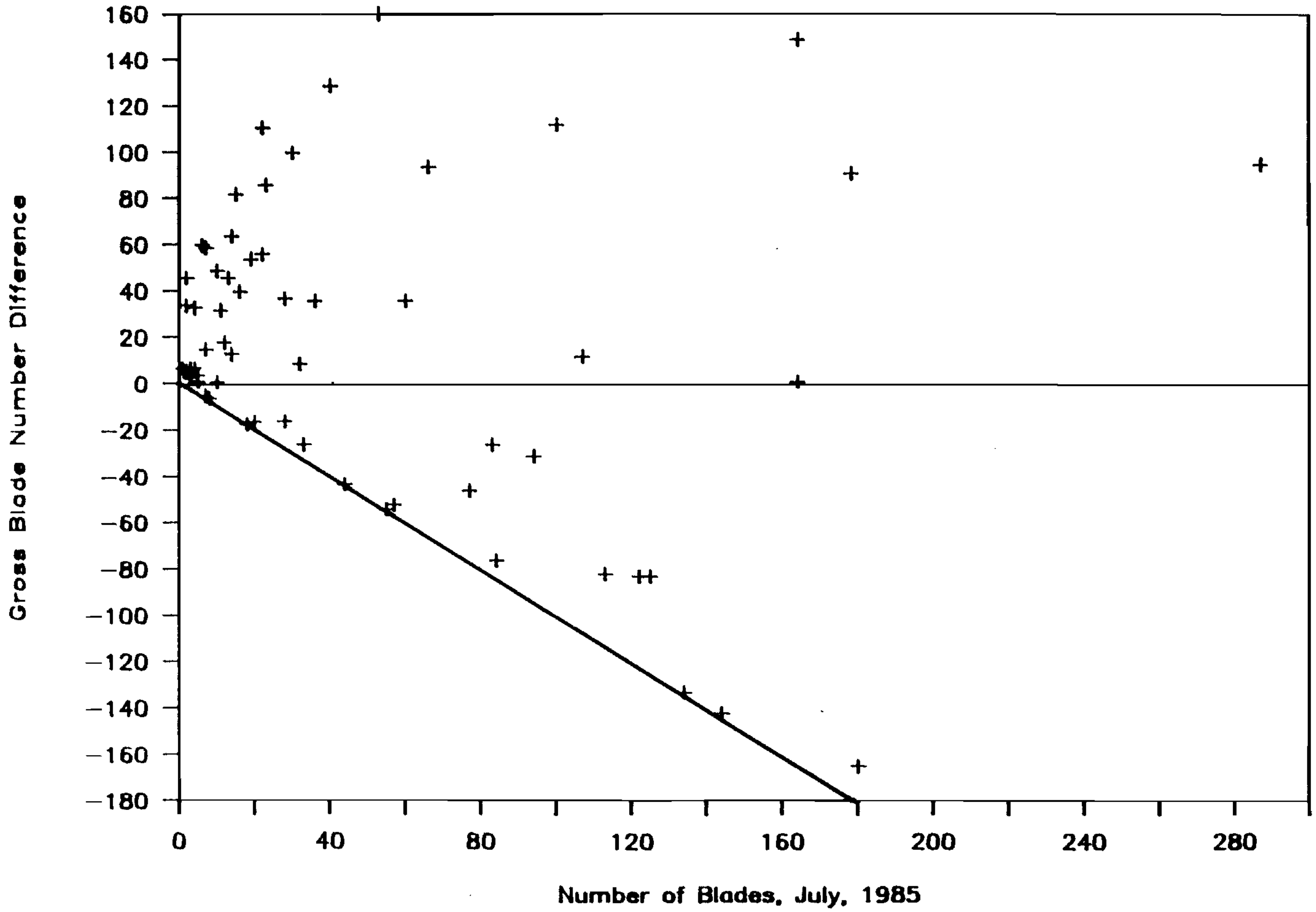

Figure 6. Scatter plot of the gross plant blade number difference of tagged *Fucus* plants between June and September, 1985.